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SULPHATE RESISTANCE OF CEMENT PARTIALLY REPLACED BY SILICA FUME

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ABSTRACT

Silica fume from a Canadian source was evaluated with regards to improved sulphate resistance when used as a supplementary cementing material. The results indicate that 10% by mass replacement of a non-sulphate resistant Portland cement by this source of silica fume provided better sulphate resistance than a CSA Type 50 sulphate resistant Portland cement.

1.0 INTRODUCTION

Silica fume is a by-product of the silicon metal and alloy industry. It consists mainly of amorphous silica particles, with a very high surface area, approximately 100 times smaller than Portland cement. Its use as a supplementary cementing material was relatively recent, but a specification for its use in concrete exists in CSA CAN3-A23.5. Ontario Hydro's M241 Specification for ready-mixed concrete allows the use of supplementary cementing materials meeting this standard when approved by the engineer. Since the use of CSA Type 10 normal Portland cement, partially replaced by supplementary cementing materials, has displaced Type 50 sulphate resistant Portland cement in many cases, it was decided to evaluate various supplementary cementing materials for their sulphate resistance.

2.0 MATERIALS

A high C_3A^1 (12.8%) non-sulphate resistant, normal Portland cement (NPC CSA Type 10, CL 70016) was used as a control mix and for partial replacement by silica fume (SF). A CSA Type 50 sulphate resistant Portland cement (SRPC, CL 69955) with a low C_3A (1.8%) was also used as a control. The silica fume (CL 69888) was obtained from SKW Canada's plant at Becancour, Quebec, as a dry, extremely fine powder. Compositions of the cements and silica fume are given in Table 1. Standard ASTM C 109 sand was used with

1. C_3A is a cement chemical notation for tricalcium aluminate: $C = CaO$, $A = Al_2O_3$,
 $S = SiO_2$, $F = Fe_2O_3$

job	file	date	report no.
42-507-053	842.2	June 20, 1990	90-126-K

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all mixes, along with de-ionized water. In some mixes, Mighty 150 superplasticizer was used to maintain a constant flow without raising the water to cementing materials (w/cm) ratio.

3.0 MORTAR MIXES

Seven mortar mixes were cast as shown in Table 2. The Type 10 normal Portland cement was replaced by 0%, 10% and 20% by mass with silica fume, while maintaining the ASTM C 109 standard w/cm of 0.485 (using superplasticizer (SP) in the silica fume mixes). In one mix (#13556), the w/cm was allowed to rise to 0.535 to maintain the constant flow where 10% silica fume replacement was used. The Type 50 sulphate resistant Portland cement was cast at w/cm = 0.465 using ASTM C 305 to determine the w/cm required to obtain the proper flow range (105%-120%). This cement was also partially replaced 10% and 20% by mass with silica fume using the superplasticizer to maintain the w/cm at 0.465.

4.0 PROCEDURES

It was decided to use the ASTM C 1012 test procedure which was specifically designed for evaluation of supplementary cementing materials.

The testing consisted of mixing mortar to a constant flow (105%-120%) and casting six, 25 x 25 x 125 mm gauge length bars fitted with length measurements studs. Companion 50 mm strength cubes were also cast. When the compressive strength of each mortar mix had reached 20.7 ± 1.0 MPa, the mortar bars were measured (initial length and mass) and immersed into a 5% sodium sulphate solution. (This solution has become the standard solution in the current ASTM C 1012-87 version.) Lengths and masses of the mortar bars were recorded at intervals of 7, 14, 21, 28 days, then monthly to one year, and then quarterly until 62 months. However, when expansions of individual sets of bars approached the critical 0.10% expansion limit, more frequent measurements were taken.

5.0 RESULTS

The strength development data for the seven mortar mixes are given in Table 2. The 20.1 MPa strength required, before bars were immersed in sulphate solution, was achieved in all cases at either 2 or 3 days of age.

The expansion data for the bars immersed in the 5% sodium sulphate solution are given in Table 3 for the NPC mixes and Table 4 for the SRPC mixes. Some data have also been plotted in Figure 1 (up to 1 year). As expected, it can be seen that the NPC bars failed the proposed ASTM 0.10% failure criteria before 91 days exposure. These bars started to crack and eventually disintegrated at an expansion of 2.64% after 161 days. However, all bars made from mixes with at least 10% silica fume partially replacing the NPC expanded much less than 0.10% after one year and also less than bars made from the SRPC mixes. This would indicate that 10% by mass replacement of a high C_3A Portland cement by the source of silica fume should provide equivalent or better performance than a sulphate resistant, low C_3A Portland cement.

From Table 4, it may be noted that the SRPC mix (#13559) bars eventually exceeded 0.10% expansion after approximately 600 days. Expansions of the SRPC mortar bars containing silica fume (#13560 and #13561) did not exceed 0.10% expansion after 62 months (1860 days), and expansions were reduced with increasing replacement levels of silica fume.

Bars made from the NPC mix with 10% silica fume (#13556) and the highest w/cm of 0.535 eventually exceeded 0.10% expansion after approximately 1770 days (59 months), but no visible deterioration was noted at 62 months (Table 3). These bars still expanded less than those made from conventional SRPC control mix.

Bars made from the 10% silica fume mix at w/cm of 0.485 (#13557) expanded much less than those made from the mix at w/cm of 0.535 (#13556), indicating that provision of good quality, low w/cm mixes is also a factor in obtaining high sulphate resistance.

Increasing levels of silica fume also reduced expansions of bars made from the NPC mixes.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Using the ASTM C 1012 test to evaluate resistance to sulphate attack, it was found that a non-sulphate resistant, high C_3A normal Portland cement could provide high sulphate resistance (superior to CSA Type 50 SRPC) if partially replaced by at least 10% by mass of silica fume.

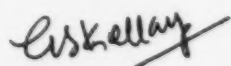
Since 10% by mass replacement of cement by silica fume is quite high in practice, it is suggested that a future study might include lower replacement levels such as 5% and 7.5%.

While 10% silica fume provides good sulphate resistance, w/cm must still be kept to the minimum to ensure good quality, low-permeability concrete.

A sulphate resistant Type 50 Portland cement was also improved by partial replacements with silica fume, even though it would meet the proposed ASTM expansion limits on its own merits.

The conclusions from this work should not be extrapolated to other sources and types of silica fume. Each source should be tested before acceptance.

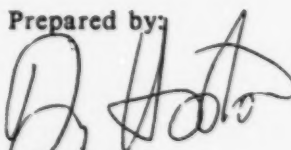
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TABLE 1
COMPOSITIONS OF CEMENTING MATERIALS

Property	T10 NPC CL 70016	T50 SRPC CL 69955	Silica Fume SF CL 69888
Oxides (%):			
CaO	63.83	63.6	0.17
SiO ₂	21.05	22.9	92.7
Al ₂ O ₃	5.73	2.80	0.17
Fe ₂ O ₃	2.01	3.64	0.29
MgO	2.56	3.31	0.59
SO ₃	2.92	2.01	0.36
Na ₂ O	0.28	0.47	0.16
K ₂ O	0.94	0.45	0.95
TiO ₂	0.24	0.15	<0.01
P ₂ O ₅	0.13	0.06	0.06
LOI	1.31	0.68	3.24
Mn ₂ O ₃	0.05	0.07	0.02
ZnO	0.01	<0.01	0.07
SrO	0.09	0.04	<0.01
Na ₂ Oeq	0.90	0.77	0.79
Relative Density	-	3.17	2.22
Blaine (m ² /kg)	-	577	6003*
Bogue (%):			
C ₃ S	44.2	53.8	-
C ₂ S	27.0	25.1	-
C ₃ A	12.8	1.8	-
C ₄ AF	6.1	11.1	-

*The true surface area of silica fume is approximately 20,000 m²/kg as measured by more accurate nitrogen sorption techniques.

TABLE 2
MORTAR MIXES AND STRENGTHS

Lab Mix #	13555	13556	13557	13558	13559	13560	13561
Cement Type	NPC	NPC	NPC	NPC	SRPC	SRPC	SRPC
% Silica Fume (by mass)	0	10	10	20	0	10	20
w/cm	0.485	0.535	0.485	0.485	0.465	0.465	0.465
SP Dose (mL/kg of cm)	0	0	3.38	6.76	0	8.11	18.92
Flow (%)	115	110	119	113	116	110	111
(ASTM C 1012 mortars are made with a sand/cement ratio = 2.75:1.0)							
Strength (MPa)							
1 day (1)*	14.7	14.0	15.7	15.9	8.4	11.7	12.5
2 day (2)	21.0	19.1	21.5	21.6	-	-	20.8
3 day (3)	-	21.4	-	-	20.3	25.0	-
7 day (3)	28.2	29.4	31.2	41.1	24.7	34.4	42.0
28 day (3)	34.2	41.8	44.2	56.6	32.0	49.5	63.8

* = number of cubes tested at each age.

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SULPHATE RESISTANCE OF CEMENTING MATERIALS

MORTAR BAR

TABLE 3

PROJECT	Silica Fume (SF)		CEMENTING MATERIALS: T10 PC CL 70016 S.F. CL 69888										
SUBMITTED BY	R.D. Hooton		DATE CAST	Nov 5-13, 1984		SOURCE		T10 = St. Lawrence, Clarkson SF = SKW Canada, Becancour, P.Q.					
DATE	May 15, 1990		DATE IN SOLUTION	Nov 7-14		FILE NO.	842.2		REPORT NO. 90-126-k				
INV. NO.	AGE IN SOLUTION (DAYS)												
	7	14	21	28	56	91	119	147	154	161	175	203	
	(6m)												
	PERCENT EXPANSION												
13555	.010	.015	.020	.024	.038	.113	.420	1.341	1.804	2.643	*	*	
13556	.007	.010	.011	.012	.016	.018	.018	.021	--	--	.026	.031	
13557	.006	.008	.011	.006	.014	.017	.015	.018	--	--	.031	.024	
13558	.007	.010	.008	.008	.008	.011	.012	.008	--	--	.031	.015	
NOTE: 1. Tested according to ASTM Designation: C1012-87 2. Specimens 25 x 25 mm prisms, effective gauge length 125 mm 3. Each test result represents the average of six specimens 4. Solution: 5% Na₂SO₄ 13555 = 100% T10 PC 13556 = 90% T10 PC/10% SF 13557 = 90% T10 PC/10% SF (with SP) 13558 = 80% T10 PC/20% SF (with SP)													
* all bars failed.												SUBMITTED	
APPROVED													

SULPHATE RESISTANCE OF CEMENTING MATERIALS

Rev. 1/80

TABLE 3 (cont'd)

PROJECT		Silica Fume (SF)				CEMENTING MATERIALS: T10 PC CL 70016 S.F. CL 69888			
SUBMITTED BY		R.D. Hooton				DATE CAST: Nov 5-13, 1984 DATE IN SOLN: Nov 7-14			
DATE		May 15, 1990				CHARGE TO 42-504-053			
						FILE NO. 842.2			
INV. NO.						REPORT NO. 90-126-K			
AGE IN SOLUTION (DAYS)									
PERCENT EXPANSION									
13555	*	*	*	*	*	*	*	*	*
13556	.031	.037	.033	.038	.042	.043	.038	.042	.049
13557	.027	.030	.026	.031	.033	.036	.033	.039	.042
13358	.016	.018	.018	.022	.023	.021	.021	.022	.022

NOTE: 1. Tested according to ASTM Designation: C1012-87

2. Specimens 25 x 25 mm prisms, effective gauge length 125 mm
3. Each test result represents the average of six specimens
4. Solution:

APPROVED

SUBMITTED

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SULPHATE RESISTANCE OF CEMENTING MATERIALS

TABLE 3 (cont'd) MORTAR BAR

PROJECT		Silica Fume (SF)		CEMENTING MATERIALS: T10 PC CL 70016 S.F. CL 69888									
SUBMITTED BY		R.D. Hooton		DATE CAST: Nov 5-13, 1984		SOURCE T10 = St. Lawrence, Clarkson SF = SKW Canada, Becancour, P.Q.							
DATE		May 15, 1990		DATE IN SOL'N: Nov 7-14		CHARGE TO 42-504-053		FILE NO. 842.2		REPORT NO. 90-126-K			
INV. NO.													
		AGE IN SOLUTION (DAYS)											
		</											

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SULPHATE RESISTANCE OF CEMENTING MATERIALS

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TABLE 4

MORTAR BAR

PROJECT		Silica Fume (SF)		CEMENTING MATERIALS:		T50 PC CL 69955 SF CL 69888							
SUBMITTED BY		R.D. Hooton		DATE CAST:		T50 PC LaFarge, Woodstock SF SKW Canada, Becancour, P.Q.							
DATE		May 15, 1990		DATE IN SOL'N:		FILE NO. 842.2							
		CHARGE TO		42-504-053		REPORT NO. 90-126-k							
INV. NO.		AGE IN SOLUTION (DAYS)											
		(6m)											
		7	14	21	28	56	91	119	147	154	175	203	231
		PERCENT EXPANSION											
13559	.005	.009	.008	.012	.018	.023	.027	.029	--	.037	.040	.044	
13560	.003	.006	.006	.008	.009	.011	.012	--	.016	.021	.018	.027	
13561	.003	.003	.004	.003	.003	.011	.007	--	.011	.014	.014	.018	
NOTE: 1. Tested according to ASTM Designation: C1012-87													
2. Specimens 25 x 25 mm prisms, effective gauge length 125 mm													
3. Each test result represents the average of six specimens													
4. Solution: 5% Na ₂ SO ₄													
13559 = 100% T50 PC													
13560 = 90% T50 PC/10%SF (by mass)(withSF)													
13561 = 80% T50 PC/20% SF (with SP)													
APPROVED								SUBMITTED					

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SULPHATE RESISTANCE OF CEMENTING MATERIALS

TABLE 4 (cont'd)

MORTAR BAR

PROJECT		Silica Fume (SF)		CEMENTING MATERIALS: T50 PC CL 69955 SF CL 69888											
SUBMITTED BY		R.D. Hooton		DATE CAST:		SOURCE T50 PC LaFarge, Woodstock SF SKW Canada, Becancour, P.Q.									
DATE		May 15, 1990		CHARGE TO		42-504-053		FILE NO.		842.2		REPORT NO.		90-126-K	
INV. NO.		AGE IN SOLUTION (DAYS)													
		(12m)													
		(18m)													
		259	287	315	344	365	421	476	532	588	602	644	700		
		PERCENT EXPANSION													
13559	.048	.052	.055	.060	.061	.067	.079	.088	.099	.102	.110	.115			
13560	.027	.031	.031	.031	.034	.036	.035	.037	.040	--	.043	.046			
13561	.017	.019	.020	.020	.022	.021	.021	.023	.024	--	.026	.026			
NOTE: 1. Tested according to ASTM Designation: C1012-87															
2. Specimens 25 x 25 mm prisms, effective gauge length 125 mm															
3. Each test result represents the average of six specimens															
4. Solution:															
APPROVED												SUBMITTED			

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SULPHATE RESISTANCE OF CEMENTING MATERIALS

TABLE 4 (cont'd)

MORTAR BAR

Rev. 1/90

PROJECT		Silica Fume (SF)		CEMENTING MATERIALS: T50 PC CL 69955 SF CL 69888												
SUBMITTED BY		R.D. Hooton		DATE CAST:												
DATE		May 15, 1990		DATE IN SOL'N:												
		CHARGE TO		FILE NO.												
		42-504-053		842.2												
INV. NO.				REPORT NO. 90-126-K												
AGE IN SOLUTION (DAYS)																
(24m)																
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756	812	868	924	980	1036	1232	1414	1687	1778	1860						
PERCENT EXPANSION																
13559	.123	.132	.139	.145	.149	.167	.168	.172	.180	.194	.198	.204				
13560	.046	.043	.047	.047	.049	.049	.054	.053	.055	.063	.063	.065				
13561	.026	.023	.026	.025	.027	.026	.031	.027	.029	.035	.033	.035				

NOTE: 1. Tested according to ASTM Designation: C1012-87
 2. Specimens 25 x 25 mm prisms, effective gauge length 125 mm
 3. Each test result represents the average of six specimens
 4. Solution:

APPROVED

SUBMITTED

ASTM C1012 SULFATE RESISTANCE OF SILICA FUME MORTAR BARS (FLOW = 115±5)

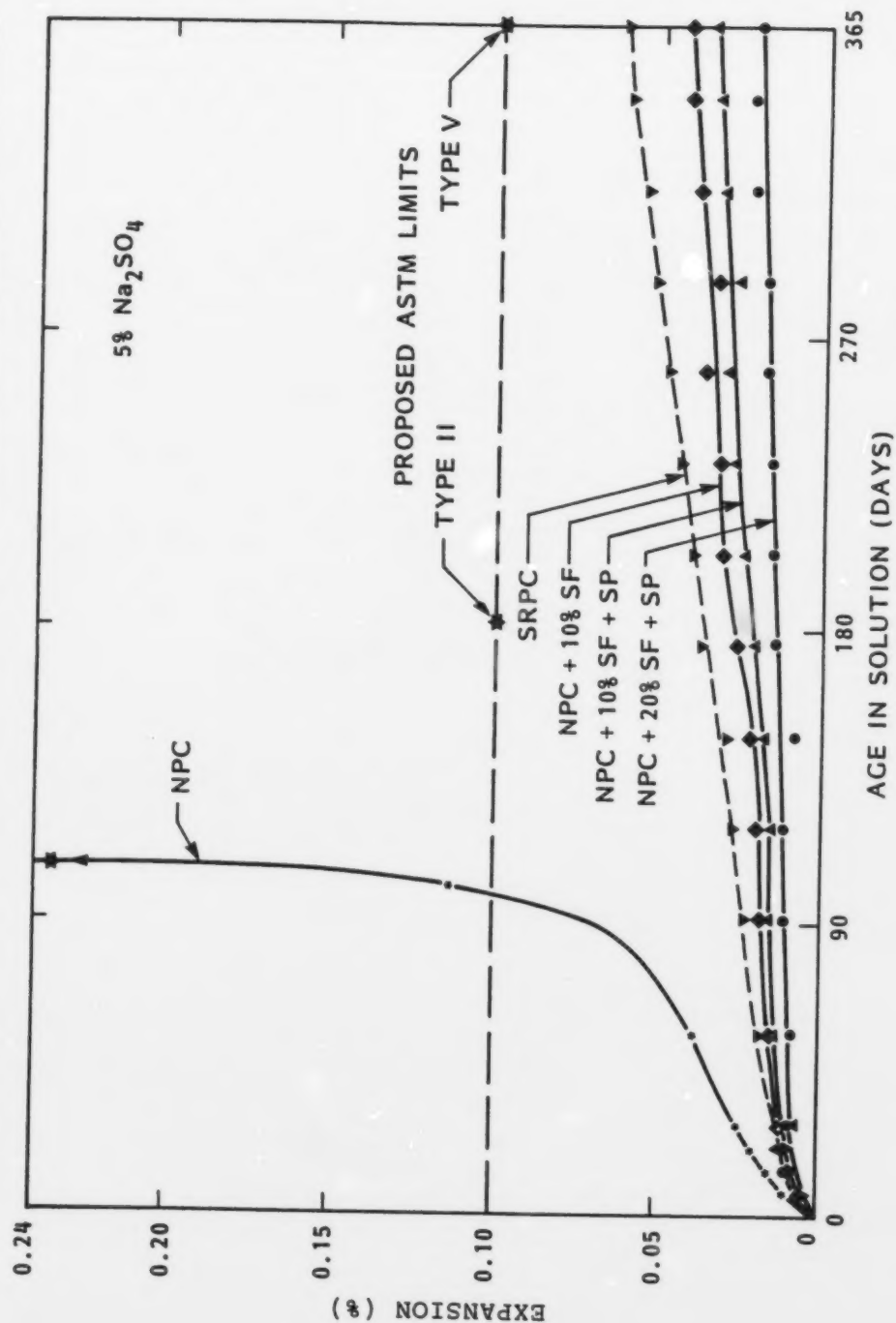


FIGURE 1